CHAPTER TWO: LITERATURE REVIEW

2.1 Biodegradable Plastics

New environmental regulations, societal concerns and increased environmental awareness throughout the world have triggered the search for new products and processes that are compatible with the environment. The guidelines for designing new products should incorporate life cycle engineering or life cycle assessment. In this way the raw materials used in the manufacture of a product and the ultimate fate of the product when it enters the waste stream has to be factored into the design of the product. Amongst the design criterion are the use of renewable resources and the biodegradability or recyclability of the product (Narayan, 2001).

Figure 2.1 shows other design criterions that are the drivers for material technology shift. The curve represents the typical economic S-curves showing slow acceptance of new technology in market place, rapid expansion and growth and finally reaching the plateau phase. The discovery of cheap petroleum causes the shift from the traditional materials towards synthetics, and now we are poised for another paradigm shift, which focused on sustainability, environmentally friendly and energy efficiency materials and others.

Plastic wastes caused great concern and biodegradability of polymers have been a research topic since the late 1960's. The challenge is to design polymers that have the necessary functionality during use, but destruct under stimulus of an environmental trigger after use. This trigger could be microbially, hydrolytically or oxidatively susceptible linkage built into the backbone of the polymer. It could also be additives that catalysed breakdown of the polymer chains in specific environment, and should be

completely utilised by soil organisms in a defined time frame (Narayan, 2001). These polymers must also remain stable during manufacture and use but break down rapidly when discarded (Scott, 2000).

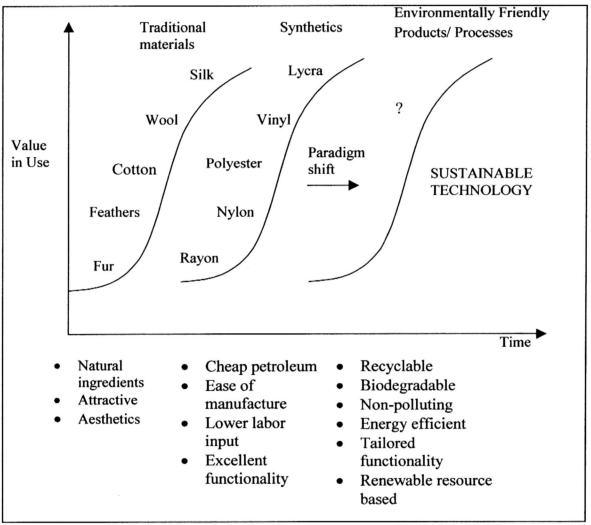


Figure 2.1 Drivers for materials technology shifts
Source: Narayan, 2000

2.1.1 Definition of Biodegradable Plastics

The definitions established by American Society of Testing and Materials (ASTM) for biodegradable polymers are probably as close to universal acceptance as any. Below is included a general and broader classification of polymers as a starting point (ASTM,1993).

"A *degradable polymer* is designed to undergo a significant change in its chemical structure under specific environmental conditions, resulting in a loss of properties that may vary as measured by standard test methods appropriate to the polymer and the application in a period of time that determines its classification."

"A *biodegradable polymer* is a degradable polymer in which the degradation results from the action of naturally-occurring microorganisms such as bacteria, fungi and algae."

"A *hydrolytically degradable polymer* is a degradable polymer in which the degradation results from hydrolysis."

"An *oxidative degradable polymer* is a degradable polymer in which the degradation results from oxidation."

"A *photodegradable polymer* is degradable polymer in which the degradation results from the action of natural daylight."

Below is the definition of *environmentally degradable plastics* (EDP) (Chellini, 2000).

- "Materials that retain the same formulation as conventional plastics during use."
- "Materials that are degraded after use into low molecular weight compounds by the combined actions of physico-chemical agents and microorganism existing in nature."
- "Materials that ultimately degrade into carbon dioxide and water."

Therefore biodegradable polymers can best be described as polymers that are able to retain its integrity during use as good as any other non-biodegradable polymer. Then it is able to disintegrate to a form where microorganisms are able to use it as food and energy and convert it into harmless substance. Basically, in order to prove the

biodegradability of these polymers it must fit into the natural carbon cycle (Figure 2.2). This way the objectives for sustainable development can be achieved.

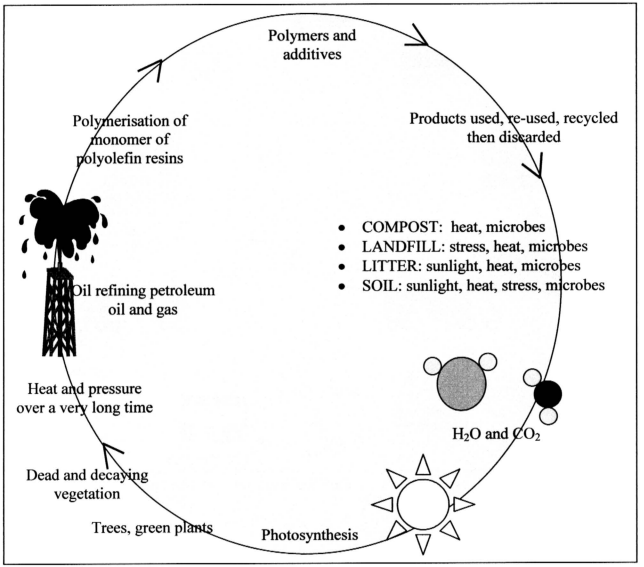


Figure 2.2 Natural carbon cycle
Source: Adapted from EPI brochure (2001)

2.1.2 Types of Biodegradable Plastics

There are two types of biodegradable plastics; natural based and synthetic based. Example of natural based plastic is produced by the American agricultural business giant Cargill and multinational Dow Chemical. Both have joined forces to turn sugar from corn into poly(lactic acid) (Figure 2.3).

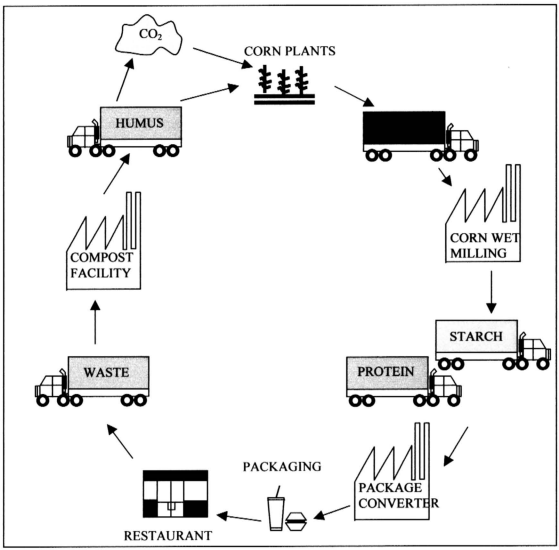


Figure 2.3 Polymer derived from corn feedstock
Source: Narayan (2001)

Corn is fermented and the result is dextrose. Further fermentation changed dextrose into poly(lactic acid) or polylactide. Then a highly efficient and versatile polymerisation process, generates a polymer which provides global economics a potentially competitive polymer to that of a conventional petroleum based polymers (Gruber, 2000). The tradename of this type of biopolymer is EcoPLA (The Star, February 2002).

EcoPLA's characteristics are almost similar with the more common thermoplastics and even some non-thermoplastic materials. For example, it is naturally glossy and

transparent like polycarbonate, polyester and acrylics. Another important characteristics is it is inherently stiff (Gruber, 2000).

Another type of natural based polymer is polyhydroxylalkanoates (PHAs). It is said to be the most promising biodegradable polymers as they degrade completely into carbon dioxide and water (The Star, February 2002). PHAs represent a range of polyesters produced from bacterial fermentation. The bacteria used are fed with sugar, oil or starch to induce the production of PHAs that are later extracted using solvents. Example of bacteria used to produce PHAs is *Pseudomonas oleovorans* (Hammond and Liggot, 1995).

Characteristics of PHAs are also similar to conventional polymer as it can be moulded into usable items. Its strength depends on the length of the sidechain. They are enzymatically degraded by a wide range of bacteria, fungi and algae. Degradation times depend on the environment and material form and can range from weeks to over a year.

As for synthetic based polymers, there are two types, one is where a biodegradable polymer is added into a synthetic polymer and the other is where specially designed additives are added into synthetic polymers to aid biodegradation.

Starch is an abundant, inexpensive and natural raw material, which permits the development of products recyclable to atmospheric CO_2 when biodegraded or incinerated. When starch is added into polyethylene films it can biodeteriorate on exposure to soil environment. The microbial consumption of starch component creates holes in the plastic matrix, increased its porosity and finally the integrity of the plastic is lost. Starch is usually added in small amounts, that is, about 6-15%. In order to

completely disintegrate the plastic, prooxidant is added which catalyses the photo- and thermooxidative process (Bastioli, 1995).

Starch-filled polyethylenes containing prooxidants are commonly used in agricultural mulch film, in bags and six-pack yoke packaging. It can be produced commercially through injection and blow moulding. Its characteristics are also similar with common plastics but with one disadvantage: reduced sensitivity to humidity. Thus, it is more suitable for niche market. Example of a promising creation is polycaprolactone (PCL) used as trash bags in South Korea (The Star, February 2002).

A polyolefin product is well known not to biodegrade since it is hydrophobic. It was discovered that oxidised, degraded polyolefin can be biodegradable. For example EPI Environmental Products Inc. manufactures a wide variety of propriety pro-degradant additives based on Totally Degradable Plastic Additives (TDPA^{TM}) technology. These additives when incorporated into polyolefin end-products which are used mainly in packaging, composting and MSW disposal will cause enhanced oxidative degradation of the products when discarded (Tung, 1999). Frequently used additives are transition metals in the form of stearates. They are so effective that they can cause degradation during processing and storage. Thus, a metal restraining is added to avoid this. Iron, manganese, cobalt, vanadium and cerium dithiocarbamates (I) are the typical examples of such "restrained" prooxidants. Consequently, by combining these two additives in polyolefins permits a wide range of polymer lifetimes to be achieved without prejudice to the normal performance of the polymers (Scott,1994). The amount of additives added depends on the application and the induction time.

2.1.3 Plastics Applications

Single use packaging is the major use of plastics because they are light, have a very good barrier properties against water and water-borne organisms. Compared to glass, plastics have an upper hand because they have a much superior impact resistance and resilience. They are also able to protect perishable product from the environment and protect the environment from corrosive and toxic chemicals. Besides that its flexibility and processability are particularly important because this show plastics can be moulded in many different shapes and used in many different applications (APME, 1999). Therefore by using biodegradable plastics, the amount of plastics going into landfill can be significantly reduced as biodegradable plastics can be composted. For example, trash bags, disposable cutlery, pre-paid card, composting bags and many other single use application plastics.

In agriculture, plastics are used as mulching films. Mulching films are sheets of plastics covering the soil at the base of plants. Advantages of using plastic sheets are, they are able to provide a conducive climate for the roots and of its durability. These films are able to increase and contain the soil temperature, retain moisture thus reducing water loss and maintain humidity throughout the growing life of the plant (Scott, 1999). This will give more yields for most crops (Table 2.1).

Table 2.1 Crop yields with and without mulching films

Crop	**Location/ treatment**	**Yield (kg)**	**Increase (%)**
Musk melons	New Brunswick / Bare ground	62.73	
(per 7 plants)	Mulched	92.64	47
Tomatoes	Oregon / Bare ground	10.5	
(per plant)	Mulched	15.2	45
Bell pepper	Rio Grande / Bare ground	1356	
(per hectare)	Mulched (mid-bed trenching)	6633	389

Source: Scott (1999)

The biggest disadvantage of mulching is the considerable cost farmers have to endure in getting rid of the films. Therefore, the ideal solution for this is to have mulching films that is able to give all advantages, retain its integrity during the growing seasons and subsequently disintegrate and biodegrade in soil after cropping. In this way the cycle of carbon will be a complete (Scott, 1999).

Another use of biodegradable plastics or polymers is in biomedical applications. The biological inertness and lightness of polymers makes them very attractive. Typical examples are in dental applications and contact lenses. The inventions of 'soft' hydrogels that absorb water and transmit oxygen are replacing hard polymers in contact lenses. Another use is as temporary sutures and supporting meshes, which are required to dissolve and biodegrade over a relatively short period of time, such as bone fracture fixation (Edelman, 1995).

Other industry also use plastics or polymer for permanent basis. Such as electrical and electronics industry, automotive industry, building and civil engineering and furniture making industry.

In electrical and electronics (E&E) industry, plastics are used widely, from casing of electrical equipment to the components of microchips. Recent development uses the latest type of plastics. As a result devices are getting smaller and lighter. This means that while the number of plastic in E&E applications increase, the weight of plastics used in each unit will decrease (APME, 1999).

In most household appliances that are operating at ambient temperatures, plastics are the modern materials of choice. For example, plastic is the main component in food mixers,

hair dryer, vacuum cleaners and television. Office equipment such as computers, chairs and other items are also made from plastic. Most of this equipment are produced by injection moulding and can be produced in large volume and accurately.

Plastics are also increasingly replacing traditional materials in automotive components. The main reason is its reduced weight. The lesser weight means less energy is required to move the vehicle. The result is savings in oil consumption. It is estimated that over the past decade 200 - 300 kg of traditional materials have been replaced by 100 kg of plastic which is equivalent to a reduction in fuel consumption of about 750 litres over the useful life of the car, which is about 150,000 km. This can also be seen in the reduction of CO_2 emission of 30 metric ton across Western Europe (Scott, 1999).

Another major use of plastic is in building and civil engineering area. The most obvious and valuable contribution is the replacement of wood in window frames and outdoor cladding. Again the choice is due to plastics resistance against biodegradation and the reduced decoration costs. Another widely used polymeric material is (unplasticised)PVC (UPVC). In our homes this materials is used mostly to bring water to the kitchen and bathrooms. Plastics are designed to be strong, durable, have low maintenance and corrosion-resistant are the advantages that will encourage the use of plastics in building and civil engineering area (APME, 1998).

In recent years polymers have assumed an increasingly important role in underground applications. These include piping, ducting and underground chambers where previously steel or concrete would have been used. For example, as impermeable membranes in the containment of water in reservoirs and of effluents in sanitary landfill,

in grids and nets in soil stabilisation and in underground electricity cables. Again its resistance towards biodegradation is the reason for preference and they have been given the general description 'geopolymers' or 'geosynthetics'. Iron and steel were once the main materials in transporting oil, water and gas underground. Their failure due to corrosion resulted in their replacement with plastics, particularly high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), polypropylene (PP) and to a lesser extent rigid PVC (Scott, 1999).

2.1.4 Biodegradation Mechanisms

Biodegradation trigger mechanisms can be divided into three actions (Figure 2.4).

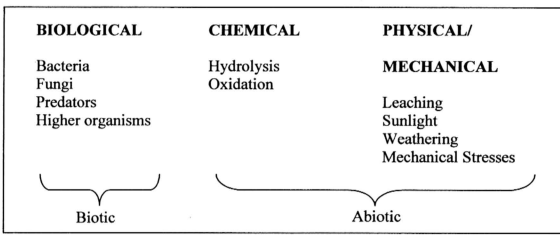


Figure 2.4 Biodegradation trigger mechanisms
Source: Scott (1999)

These actions can take place individually but in majority of cases a combination of biotic and abiotic attacks does take place. In the latter cases the abiotic actions take place first then only biotic attack occurs.

For example, for synthetic polymers the biodegradation of polymers occurs by two quite distinct mechanisms depending on the nature of the polymer and the environment. The first is abiotic hydrolysis followed by bioassimilation (hydro-biodegradation) and the latter is the primary process involved in the biodegradation of the hetero-chain polymers

such as aliphatic polyesters of which poly(lactic acid) (PLA) and poly(3-hydroxylalkanoates) (PHA), are typical examples. Normally peroxidation plays a secondary role in these polymers. It has recently been proven that photooxidation can accelerate hydro-biodegradation. These hetero-chain polymer breaks down into monomers and oligomers. Hydro-biodegradable polymers are suitable for cosmetics and personal hygiene products, and they normally end in sewers. They are not suitable for packaging films or agricultural films (Scott, 2000).

The second mechanism is peroxidation followed by bioassimilation of products (oxo-biodegradation) of lower mass and it applies particularly to the carbon chain polymers. The use of appropriate antioxidants can control the rate of abiotic peroxidation and hence biodegradation. This means that the mechanical properties of plastic products can be retained for months or sometimes years without fragmentation in the outdoor environment. This, however, can be changed when it is exposed to some components of the environment for example light or heat. Once the molecular weight has reduced, bioassimilation begins. Since this is much faster than the peroxidation process, the latter is the rate-controlling step in the overall biodegradation process. The products resulting from peroxidation are carboxylic acids and alcohols (Scott, 2000).

The oxidation of polymers is dependent both on its chemical structure and its morphology. In general the polyunsaturated rubbers are very susceptible to oxidation due to the presence of the olefinic double bond in the polymer back-bone and the absence of crystallinity. In this project the samples are polyolefins. These are much more stable because they contain relatively few double bonds. Their inherently oxidisability depends on the number of tertiary carbon atoms in the chain, thus the order of oxidisability is polypropylene (PP) > low density polyethylene (LDPE) > high

density polyethylene (HDPE). However, HDPE and PP have a higher degree of crystallinity than LDPE, thus they undergo chemicrystalisation and embrittlement more rapidly than LDPE (Scott, 1995). Thus in order to enhance the degradability of polyethylene, chemical or photo initiators or both are added to plastic films. For example, by using transition metal compounds as a prooxidant that catalyses the photo and thermooxidative process. Therefore in the presence of oxygen these prooxidants initiate polymer degradation by producing free radicals which react with molecular oxygen and possibly with the carboxyl and ketone groups in the oxidised polyethylene (Khabbaz et al, 1999) and one of the products is carboxylic acid (Figure 2.5).

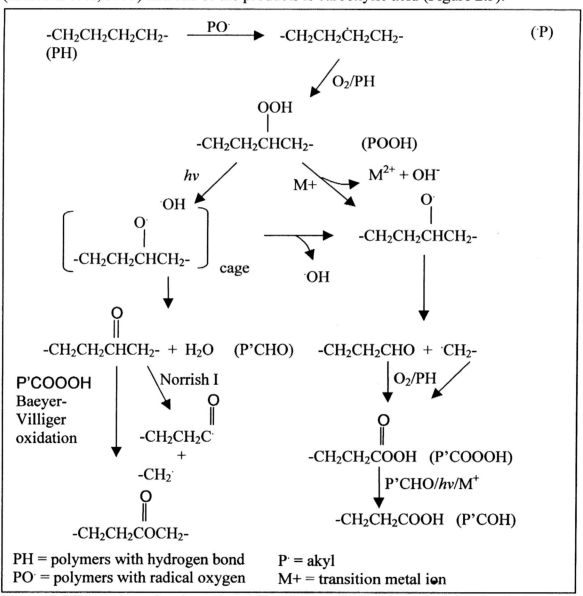


Figure 2.5 Formation of carboxylic acids and esters in the oxidation of polyethylene
Source: Scott (1995)

As mentioned before in the definition, biodegradable plastics must retain its integrity during use and disintegrate after. Figure 2.6 shows the changes in the properties of ideal degradable plastic over time.

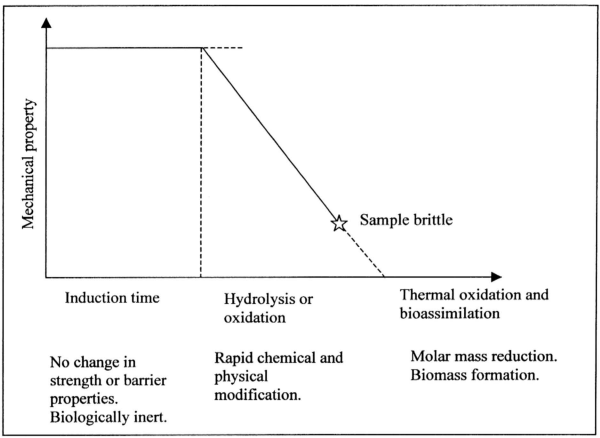


Figure 2.6 Properties of the ideal degradable plastic
Source: Scott (1999)

The induction period is when no change occurs in the mechanical properties. The timing is very important as not to disrupt the benefits of using the polymer. For example, if mulching films disintegrate during growing season, there would be irreparable disruption of the controlled ecological environment of the growing plants due to ingress of rainwater with associated loss of nutrient control. Loss of moisture by evaporation in dry climates, due to breakage of the film or by water diffusion through it, also leads to dramatic reductions in crop yield. On the other hand, delayed breakdown of the plastic can be similarly costly due to physical impairment of the soil texture and to clogging of farm machinery by incompletely degraded plastic.

Mulching films degrade due to sunlight exposure or photooxidation. Under slight pressure the plastic becomes brittle. This point has been defined in terms of stress-strain characteristics as 95% loss of the original elongation at break. The timing for this should ideally be short as possible and most importantly it should lead to complete fragmentation of the plastic (Scott, 1994).

2.1.5 Characterisation of Degradation

Degradation can be monitored physically and chemically. These changes can be monitored early especially during ageing, for example by the observation of new functional groups in Fourier Transform Infrared Spectroscopy (FTIR) spectra. The easiest way to detect degradation is to measure the weight loss. This gives a rough guide to percentage degradation of the materials. Another method is to check the molar mass reduction using Gel Permeation Chromatography (GPC). Other method is to check the loss of tensile properties using Instron tensile test machine for mechanical properties degradation (Karlsson and Albertsson, 1995).

Differential scanning calorimetry (DSC) is used to check on changes in melting temperature and glass transition temperature. Scanning electron microscopy is used to check on changes on morphology and crystallinity. Chemiluminsence (CL) is a very sensitive technique and the intensity of emission is dependent on the extent of oxidation of the polymer. Gas chromatography (GC) and liquid chromatography (LC) together with mass spectroscopy (MS) are used to detect traces of monomers, initiators, additives and degradation products. These methods are shown Figure 2.7.

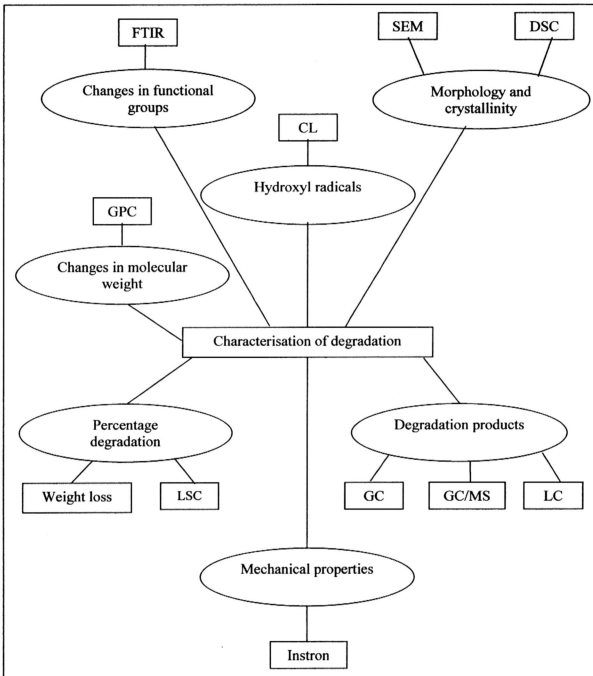


Figure 2.7 Techniques to determine polymer degradation
Source: Karlsson and Albertsson (1995)

2.1.6 Composting

Biological recycling is one of the waste management options and composting is an example of biological degradation. It is an environmentally sound approach to transfer biodegradable waste, including the new biodegradable plastics, into useful soil amendment products. Composting is the accelerated degradation of heterogeneous organic matter by a mixed microbial population in a moist, warm, aerobic environment under controlled conditions. Composting produced valuable compost along with water and carbon dioxide. The carbon dioxide does not contribute to greenhouse gases because it is already part of the biological carbon cycle. Polyolefin degradation mechanism involves oxidation and composting gives the option of diverting plastic wastes from landfills (Narayan, 2000).

By incorporating compost into soil, it can increase the organic content of the soil and can improve its texture, nutrient content, and water retention and aeration capacities. Other application including as a top dressing, mulch and landfill cover (Diaz, 1993). In addition to that the benefits of compost-amended soil include reducing the need for additional chemical inputs, suppressing plant disease and increase earthworm and micro-organism biomass as much as fivefold (Narayan, 2000).

More than 60% of MSW in Malaysia is organic in nature and potentially compostable. Composting is one of the options to divert waste from landfill. Consequently, the use of biodegradable polymers in the packaging of organic or biodegradable materials, such as food, enables this waste to be directly composted without the need to separate the contents from the packaging.

2.2 Plastic Waste Management

The current practice in most countries including Malaysia is to dump plastic waste and other domestic and some industrial packaging materials into landfills. It has a number of disadvantages.

i. Land for landfill have become increasingly scarce and for political reasons, landfill levies are set to rise sharply in all developed countries since municipal waste has to transported a greater distances with associated wastage of energy and increase in final cost (Scott,1999).

ii. Domestic and industrial wastes contain a variety of toxic materials such as heavy metals and organic chemical wastes that can leach inside landfill without lining (Scott,1999).

iii. Putrecible residues such as biological wastes slowly biodegrade, primarily anaerobically, to give biogas. This biogas consists primarily of methane which is 25.4 times more lethal than carbon dioxide as a greenhouse gas (Scott,1999).

iv. Plastic garbage sacks retards the assimilation of waste by microbes by restricting the ingress of water and air (Wiles et al, 2000).

v. Plastic garbage sacks also pro-long the after care period of a landfill site (Wiles et al, 2000).

vi. Landfill is an unhygienic option of dumping waste as it can attract flies and rats. Besides that it can cause fire and odour.

From all the disadvantages listed above, clearly landfill should be the last option and be reserved for wastes that have no fuel or other industrial value for example residues from incineration after the full fuel potential of the organic materials have been realised. Therefore other disposal and recycling methods should be considered as to divert as much plastic wastes as possible from landfills. By following the hierarchy for waste disposal, the amount of plastic wastes into the landfill can be reduced or eliminate. For

example, in Malaysia the Housing and Local Government Ministry launched the 3R Program (reduce, reuse and recycle). This program emphasises on 3 things in order to reduce wastes going into landfills. The first thing to do is to try and reduce the use of plastic containers especially packaging product. For example, bringing your own bags or carton boxes to supermarket to fill in the groceries and get a small discount from the supermarket for the effort. This has already been done in Sainsbury, a hypermarket in United Kingdom. Some plastic container can be reuse, for example ice-cream plastic container that can be used to keep leftover food, nails and other loose things lying around in the house. Some plastic especially uncontaminated single polymer can be recycled and be used as park benches for instance.

Other activities can also be done in order to achieve proper environmental management, which are (Bisio and Xanthos, 1995):

i. Waste prevention through use of proper parts or product design techniques and manufacturing processes.
ii. Reuse of plastic and composite parts or products.
iii. Waste management through recovery or recycling (reprocessing), chemical or fuel conversion, waste to energy combustion units and landfilling.

2.2.1 Life-Cycle Engineering

" It is no longer physically possible to externalise the environmental costs and damages outside the production process and allow them to be borne by nature and future generations: industrial processes and products must be redesigned to internalise such costs and damages within the production and consumption process" quoted from The Limits of Competition by The Group of Lisbon, (1995).

Countries all over the world experience growth, with it comes the rapid use of natural resources to make consumer goods. This is unavoidable, thus there is a strong pressure to use natural resources appropriately while continue to have economic growth in order to achieve a sustainable growth (Lundquist, 2000). Besides that we can no longer burden the place where we live with more pollution.

As mentioned earlier plastic waste is increasing every year. One of the preconditions for further growth of plastic applications is that the implementation of new technology should improve the efficiency of resource consumption and reduce waste output. To be more effective, improvements should occur at all stages of the life cycle of a product, from raw material production, part manufacture and use to recycling or disposal (Lindquist, 2000). Life-cycle engineering (LCE) provides the methodology of how to design, manufacture, use, maintain and recover materials and products with the aim of optimising resource use and minimising environmental impact (Figure 2.8).

Thus, by using LCE the plastic industry can contribute towards sustainable development through achieving the items below (APME, 1999):

i. less energy used and fewer emissions produced during manufacture of raw materials
ii. low energy production processes and in-house recycling of production waste which maximise resource efficiency during product manufacture
iii. technological innovation resulting in more eco-efficient designs using less plastics to do more
iv. plastics' light weight or strength and durability giving a longer life-span
v. maximising post-use plastics waste recovery by diverting valuable resources from landfill for mechanical and feedstock recycling, (where environmentally and economically feasible) or by recovering energy in the form of hear and / or power.

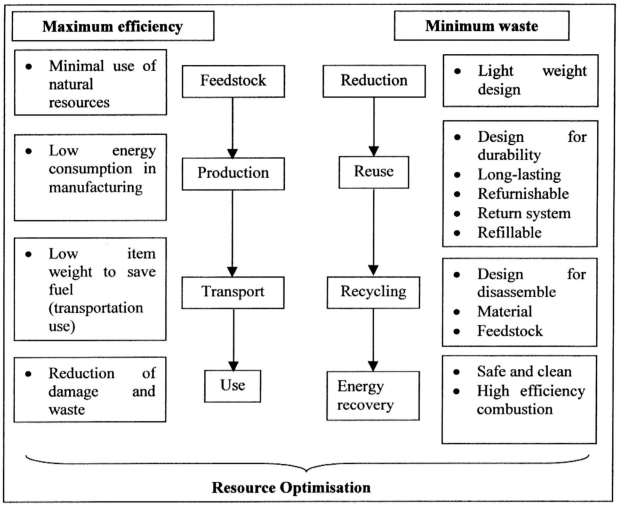


Figure 2.8 Life cycle engineering practices
Source: Lindquist (2000)

There are four environmental parameters to be considered: energy consumption, air pollution, water pollution and waste production. These are invoked to assess the ecological impact of plastic packaging, for instance. For energy consumption, every kind of energy must be considered, such as electrical, thermal and traction power used in extraction, transformation and transportation of raw materials and waste treatment to make it a safe environment. Air pollution is measured in volume (m^3) of pure air that must be added to gas emissions to conform to existing regulations. As for water it would be measured in volume (m^3) that should be used to dilute liquid emissions produced. Both air and water pollution measurements should be over the whole life cycle of the product (extraction, production of electrical and thermal energy and

transportation). The concept goes equally for waste production where it is measured in volume (cm^3) for each stage in the manufacture, use and disposal (Scott, 1999).

LCE provides us with the tool to achieve activity number one, which is waste prevention. This is because it helps manufacturers by providing information that minimises energy and pollution avoidance costs in his own manufacturing processes. Reuse of plastic and composite parts or products can be applied to plastic manufacturers themselves. One should consider whether it is possible to reuse the plastic and composite parts and systems after they have been removed from service. For example Xerox Corporation has shown that it is possible to significantly reuse plastic parts in copiers both as replacement components and in new equipment (Bisio and Xanthos, 1995).

Finally for the third activity, plastic waste management (Figure 2.9) is important as not to burden the environment. There are many different types of plastic, thus each has its own post waste potentials. In order to fully utilise the post waste potential values, a suitable waste treatment should be used. For example, thermosetting plastic waste are not suitable for recycling as the products after recycling is not suitable for robust use. However, the calorific values for thermosetting plastic is high, thus making it more suitable for energy recovery option. This means, a good combination of plastic waste management, covering the many different types of plastics, will give the optimal balance of environmental, economic and social factors and ensure maximum recovery.

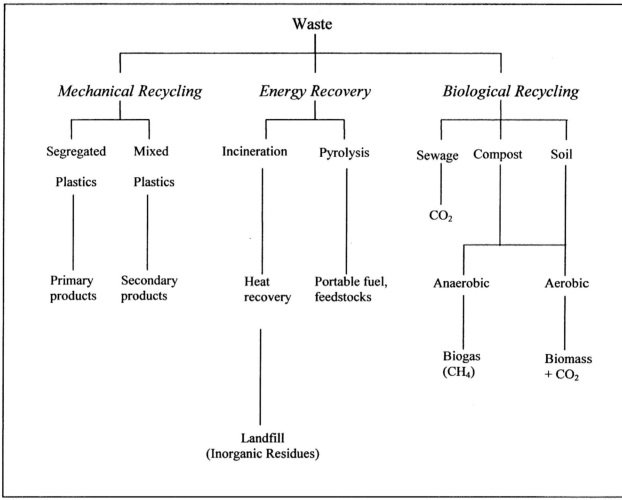


Figure 2.9 Plastic waste management options
Source: Scott (2000)

2.2.2 Mechanical Recycling

The basic argument behind plastic recycling is to gain some of the energy invested in the raw materials of polymer industry and in their conversion into commercial artefacts. In Malaysia plastic recycling is extremely very low, less than 1% (The Star, April 2001). In Western Europe, mechanical recycling has the potential to double, from 1.2 million tonnes in 1995 to 2.7 million tonnes by 2006 (APME, 2000). In United States the between 1996 and 1997 the amount of plastic bottle recycling has increased around 4%. Even though the amount of plastic recycling shows potential growth, the recycling

rate has declined. Recycling rate is the amount of total production and consumption of virgin plastic resins against the amount of plastic recycled. The recycling rate has declined because the weaker demand for recycled resins in an economy where the virgin resins are priced very low. This situation is due to poor global economy compounded with low energy costs in 1999 (Subramaniam, 2000).

The plastic waste is divided into two types: segregated plastics and mixed plastics. Segregated plastics are clean plastics that are recovered from the waste stream bulk, for example, industrial shrink wrap, battery cases, crates and car bumpers. This can be easily recycled with the addition of new antioxidants and UV stabilisers into primary applications without significant loss of mechanical properties. Mixed plastics are more difficult to recycle because they are a mixture of main polymers and are contaminated with foodstuff. In order to recycle, complex processes are developed such as Reclamat process, Reverzer process, Remaker process, Flita process and Klobbie process (Scott, 1999). Almost all of the products from the above processes are not as durable as the original products.

Plastics are not like glass or metals, where they can still gain the same properties like the original products. This is because polymers are organic materials thus, every time they are re-processed there is a loss in physical and mechanical properties due to peroxidation, especially for mixed plastics (Scott, 2000).

Sorting plastics waste is important in order to meet the goals of specific recycling programs. Sorting can be the most difficult and dirty job if it is being carried out by poorly paid and often volunteer individuals who faced the unpleasant environment to manually segregate bottles and cans contaminated with foodstuff. They sort waste

according to generic resin type and colours. These days it is easier as plastics packaging are coded and embossed onto the products. Sorting can also be done at home, commercial firms and institutions; at pickup points during the collection of waste streams and at facilities that separate and prepare bulk shipments of segregated plastic objects for reclamation. Hand sorting is still used up to now. Besides that mechanical sorting such as gates and air streams have been used to a limited degree (Bisio and Xanthos, 1995). Automated sorting equipment has already been used in Japan.

Recycling requires a lot of energy, which include energy used in sorting, transportation, cleaning and reprocessing. Thus, this actually defeats the ecological and economical benefits of recycling. A study was undertaken in 1999 to provide the first 'eco-efficent' evaluation of a number of European waste management scenarios. The study concluded that too great emphasis on recycling as a recovery option for plastics packaging could drive Europe to ever increasing waste management costs with limited environmental gain (APME, 1999). Figure 2.10 shows the results of a study done at several scenarios in order to show the economic impact. The scenarios can be described as:

i. Landfill 100% landfill

ii. 1997 the situation - 15% recycling (12% mechanical and 3% feedstock), 15% energy recovery and 70% landfill,

iii. I 15% recycling (mechanical) 85% energy recovery,

iv. II 25% recycling (15% mechanical and 10% feedstock) and 75% energy recovery,

v. III 35% recycling (25% mechanical and 10% feedstock) and 65% energy recovery, and

vi. IV 50% recycling (35% mechanical and 15% feedstock) and 50% energy recovery.

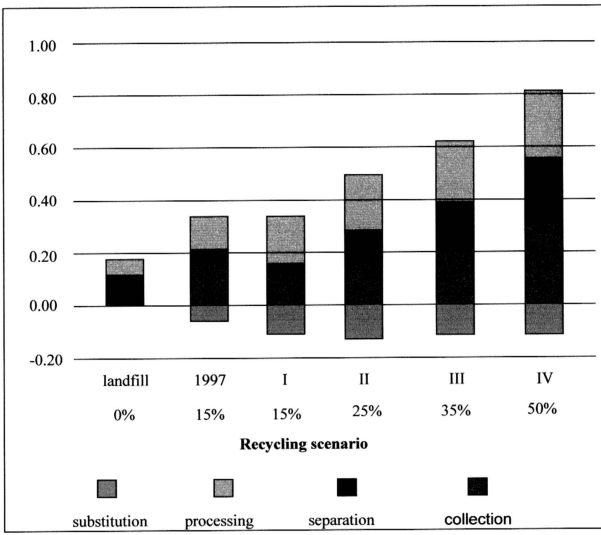


Figure 2.10 Cost balance for recovery of source separated household plastics packaging and industrial waste

Source: APME (1999)

Figure 2.10 provides cost balance for the recovery of source separated household plastics packaging and industrial waste across the range of scenarios. Costs are shown above the 0.00 line while credits (for example those achieved through substituting virgin plastics with recycled plastics or generating heat and or electricity from waste rather than from fossil fuels) are shown below the 0.00 line. From here it is clear while costs tend to increase proportionally to the amount of recycling done, credits quickly level out after 15% recycling. In addition to this, the most significant contributing factor to high costs is the need to collect and separate waste for recycling.

The benefits of recycling should not in any way be clouded by environmental pollution and high costs. Thus the study in searching for the best eco-efficiency of platics waste management is showed in Figure 2.11. The eco-efficiency of any given waste management scenario is greater when it is the closer to the top right hand corner of the diagram. This represents the lowest environmental impact and lowest economic cost. From here it is concluded that 100% landfill has the highest environmental impact, but currently represents the lowest cost option. On the other hand, 50% recycling has the least environmental impact but the highest cost option. 15% recycling with energy recovery gives the best balance between environmental impact and cost compared with the current average situation (APME, 1999).

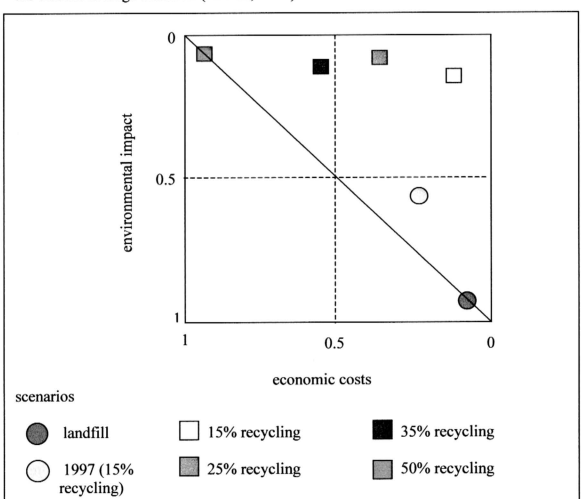


Figure 2.11 Eco-efficiency of plastics packaging waste management
Source: APME (1999)

Improving recycling plastics rates faced two main constraints:

i. the imbalance between the waste collectable and the potential end-markets for the recycled plastics

ii. the presence of large quantities of mixed plastics waste where the difficulties and energy consumed in separating into homogenous fractions and cleaning outweigh the environmental gain of mechanical recycling.

Therefore in order for mechanical recycling to offer true environmental benefits, a number of factors must be taken into account:

i. post-use waste must be easily collected and sorted

ii. the recycling process itself does not require excessive use of resources to produce recyclate

iii. sufficient demand from end-market users for recycled material is a vital pre-requisite and a key factor in determining demand is that the use of recycled materials does not compromise product safety of performance

Other plastic recycling technologies can also be used to some suitable plastics. This is a process where plastics is converted back into basic chemical used to manufacture new plastics (APME, 1999).

Energy recovery is suitable for the majority of light weight, unsorted and dirty plastics which are not suitable for recycling. In order to attain balance between environmental impact and cost, energy should be recovered, especially, in densely populated areas. Improving the efficiency of energy recovery technology should be able to contribute significantly towards environmental sustainability at low cost.

2.2.3 Energy Recovery

Some plastic waste is not suitable for recycling. In order to further divert the waste into landfills, plastics can be incinerated or pyrolysed. This is because plastics in general are organic materials that have a reasonably high energy content. Table 2.2 shows the calorific values of plastics compared with conventional fuels.

Table 2.2 Calorific values plastics compared with conventional fuels

Fuel	*Calorific value (MJ/kg)*
Methane	53
Gasoline	46
Fuel oil	43
Coal	30
Polyethylene	~43
Mixed plastics	30 – 40
Municipal solid waste	~10

Source: Scott (2000)

Besides diverting waste from landfill, it is a way to recover the energy value of products after their useful life. One such method involves combustion of municipal solid waste (MSW) in waste-to-energy (WTE) facilities. Modern energy recovery facilities burn solid wastes in special chambers, and use the resulting heat to generate steam and electricity. This process can also reduce the MSW volume by 90% (Subramaniam,2000).

Among the items that are found in MSW, the energy content of plastics is higher than any other items (Table 2.3).

Table 2.3 Energy values of common materials in MSW

Material	MJ/kg
Plastics	
Polyethylene	46.29
Polypropylene	46.17
Polystyrene	41.40
Rubber	41.40
Newspaper	18.61
Leather	16.75
Wood	15.58
Average MSW	10.47
Yard wastes	0.70
Food wastes	6.05

Source: Subramaniam (2000)

Incineration is the preferred energy recovery option of local authorities for example in Japan because they can gain financially by selling waste plastics as fuel (Huang, 1995). In order to do that the heat generated must be used locally for maximum efficiency. Therefore in some highly populated centres, they have small but efficient combined heat and power incinerators to produce electricity and as well as provide neighbourhood heat from the waste stream (Scott, 1999).

Even though incineration has its economic and social benefits, public in most developed countries distrust incineration. This is due to health concerns from its air emission. One of the products produced by burning plastic waste containing chlorine is dioxin. Dioxin is one of the most toxic chemicals known. In September 1994, the United States

Environmental Protection Agency (EPA) released its public review draft of the Dioxin Reassessment, which clearly describes dioxin as a serious public health threat. This is further stressed by a report by the International Agency for Research on Cancer (IARC), which concluded that dioxin can cause cancer in humans (McGregor, 1998). EPA has also study the cycling of dioxin through the environment, which clearly stated that dioxin, can get into the food supply (EPA). This leaves human vulnerable to dioxin exposure. Among the health effects are, breast cancer for women, testicular and prostrate cancer for men. Even babies can be exposed to dioxin, as it can be passed through breast milk.

A study commissioned by Association of Plastics Manufacturers in Europe (APME) was done from 1992 to 1998 to show to the public the benefits of combustion of plastic packaging in MSW and the way to reduce dioxin emission.

This study showed that, there could be an improvement in combustion efficiency together with an overall improvement in combustion stability when plastic packaging material was added to MSW. This depends on the quantity added. The level of unburned carbon in the residues and in the gas phase is the primary criterion and indicates the quality of the combustion operation. If the level of the total carbon is relatively high, the degree of combustion is insufficient. There are three different feed conditions as shown in (Table 2.4):

Table 2.4 Different feed condition scenarios

A	Normal MSW which contained a MPW* content of 8.5 to 12 wt% of the total MSW	Base case
B	MSW + additional 7.5% by weight mixed plastics	Medium polymer case: 16 to 19.5 wt% MPW
C	MSW + additional 15% by weight mixed plastics	High polymer case: 23.5 to 27 wt% MPW

*is a typical so-called mixed plastic waste (MPW) in Germany, which was part of the normal MSW (around 8.5 to 12 wt% from the total MSW)

The effects of plastics on the composition of incineration flue gases were assessed over a three-month period. Gas emission level measured on gases from typical MSW (base case), and on those from MSW containing medium (B) and high levels (C) of polymer appear in Table 2.5. The CO concentration in the high polymer case (7 mg/m^3) was less than the base case (19 mg/m^3). This clearly demonstrated the excellent burn out achieved in the gas phase. This is in line with the generally improved stability of combustion achieved by adding plastic waste.

Table 2.5 Clean gas emissions during packaging co-combustion

	Base Case A	Medium Polymer B	High Polymer C
CO (mg/m^3)	19	18	7
HCl (mg/m^3)	23.5	22.4	21.4
SO_2 (mg/m^3)	19	9.0	<5.0
NO_2 (mg/m^3)	405	385	410
Dust (mg/m^3)	2.4	<2.0	2.4
Furnace temp. (°C)	890	892	894

Source: APME (1999)

The quality of the MSW incineration can be seen from the level of unburned carbon in the residues and the gas phase. For instance, if the level of the total organic carbon is relatively high, the degree of combustion is insufficient.

Figure 2.12 shows the effect of the addition of plastics on several residues. For example, the average TOC values of grate ash quality reduced from 1.4% (by weight) to 0.7% (by weight) in grate ash by the addition of 15% (by weight) plastic in the feed. The

improvement of grate ash quality by about 50% TOC can be explained by the differences in combustion behaviour. A higher polymer concentration increases the volatility of the fuel leading to more homogenous combustion behaviour and better grate ash quality. Thus leading to a higher combustion operation.

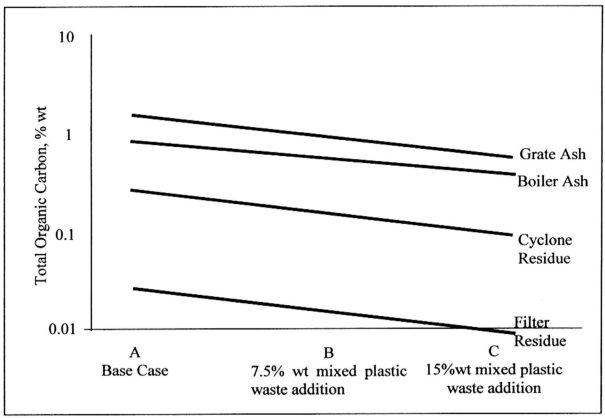


Figure 2.12 Influence on residue burn out
Source: APME (1999)

The public is more concerned about the air emission. In the same study, trials were done to check on air emission and it is possible to balance the dioxin and furan components within the emission control section. One way to control the polychlorinedibenzo-dioxins/furan (PCDD/F) clean gas concentration depends on the neutralisation additive used in the dry scrubbing system. The addition of a 5 wt% active-carbon containing lime guarantees a very low emission level. Another way is to have a longer residence time. Figure 2.13 shows PCDD/F balance without additional plastic and Figure 2.14 shows PCDD/F balance with additional plastic. The MSW content was the typical value found in Germany in 1992.

Using mass balance and six-hour mean data on the concentration of tetra- to octa-CDD/F, the flux of these components expressed in mg/h can be calculated. For Figure 2.13, in the base case (A) without plastic waste addition, the total PCDD/F in input streams was 93.9 mg/h, whereas 24.4 mg/h of tetra- and octa- CDD/F were found in the output streams. The balance showed the minimum destruction efficiency of dioxins is about 75% under normal operating conditions. The distribution of outgoing components are 7, 1, 20, 66, and 6% for the residues from the grate, boiler, cyclone, filter and chimney. From the process streams, the residues from filter and cyclone contained the highest tetra- and octa-CDD/F (66 %and 20%). The residues from here are safely disposed in special classified landfill, thus do not contribute to pollution.

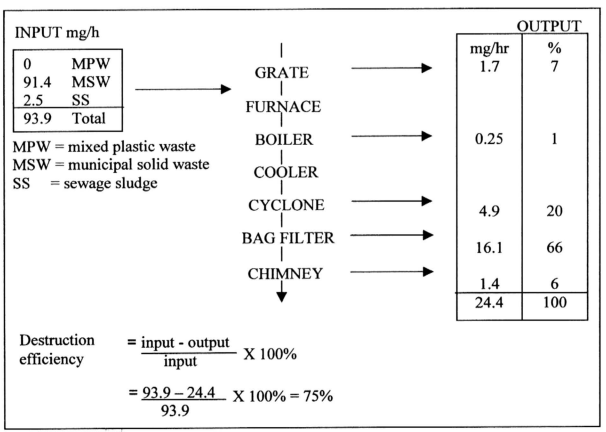


Figure 2.13 PCDD/F balance base case without additional plastics
Source: APME (1999)

In comparison the addition of plastic showed an increase of PCDD/F destruction efficiency (Figure 2.14) from 75% to about 78% for medium polymer case (B) and 81% for high polymer case (C) (refer to Table 2.8). Higher combustion efficiency as proven earlier through better burn out residues, supports this increased in dioxin and furan destruction efficiency. Thus with this knowledge together with the addition of 5 wt% active-carbon containing lime guarantees a very low PCDD/F emission level.

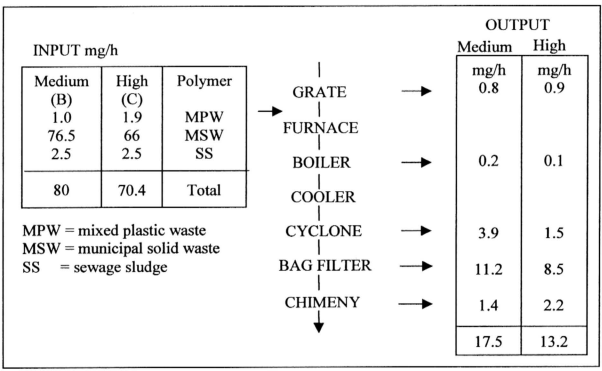


Figure 2.14 PCDD/F balance with additional plastics
Source: APME (1999)

Most of energy produced from power stations use coal. Coal is not a renewable resources, thus to reduce the dependency on non-renewable resource, a study on coal substitution was done. Here coal was substitute with plastics and paper separated from household waste for co-combustion with coal in power stations currently fuelled by coal alone.

It was concluded from the study that substituting coal with plastic waste that cannot be sensibly recycled would make a major contribution to EU energy production, equivalent

to fifteen per cent of total EU coal imports. The study also found that energy recovered from plastics and paper waste at existing power stations that are already using pulverised coal need no extensive new infrastructure to accommodate the new system. In addition to these benefits, the total environmental impact of coal substitution has been shown to be as good as a material recycling process developed by Texaco for the gasification of plastic waste (APME, 2002).

Table 2.6 shows the environmental impact of different recovery methods per tonne of post-separated plastics waste. Negative value means there is a relative environmental benefit. It is clear from here that there are the substantially reduced emissions of greenhouse gases such as CO_2 and the reduced consumption of fossil fuels.

Table 2.6 Environmental impact of different recovery methods per tonne of post-separated plastics waste

	Plastic substitution for coal at electricity plant	**Texaco gasification process**
Primary energy (GJ)	-32.2	-38.4 - -38.2
Climate change (kg CO_2 eq)	-510	812 – 833
Acidification (kg SO_2 eq)	-1.34	-0.67 - -0.74
Eutrophication (kg PO_4 eq)	-0.32	-0.17 - -0.15
Hydrocarbons (kg hydrocarbons)	-0.02	-0.20 - -0.19
Diffusion (kg polluted environment)	-1.03E+09	-1.46E+08 - -1.32E+08
Disposal (kg final solid waste)	0.1	negligible

Source: APME (2002)

Another positive outcome is the reduced amount of waste going into landfill. Thus the use of plastic as a substitute for coal not only sustained the natural resources but will also provide economically viable source of energy production, using one of the most popular materials for household products (APME, 2002).

Pyrolysis is a non-oxidative process under carefully controlled conditions, thus the formation of dioxin is much reduced. Pyrolysis converts plastic wastes to low molecular weight hydrocarbons for use either as portable fuels or as polymer feedstocks (Scott, 2000). Waste hydrocarbon polymers are similar in chemical structure to mineral oil and on heating to high temperatures they 'crack' to give a mixture of lower molecular weight hydrocarbons (Table 2.7). Some of it has the utility as chemical feedstocks for example olefins and as fuels. Pyrolysis can be carried out in fluidised bed furnaces. The gaseous effluent is treated the same way as incineration effluents.

Table 2.7 Composition of gaseous products from pyrolysis of mixed plastics (wt%)

	Temperature (°C)		
Product	*680*	*735*	*790*
Hydrogen	0.667	0.683	1.868
Carbon monoxide	8.376	14.115	6.316
Carbon dioxide	20.418	20.807	3.38
Methane	16.734	22.661	49.491
Ethene	18.383	20.690	25.994
Ethane	10.118	7.189	7.765
Propene	13.758	7.797	3.311
$C_3 - C_9$ hydrocarbons	11.546	6.504	4.875

Source: Scott (1999)

2.2.4 Biological Recycling

Nature's "waste" is returned to the natural carbon cycle by biodegradation. The primary product is biomass, which acts as a seed-bed for new growth. Time taken for degradation varies due to the complexity of biological litters. When it is fully assimilated into the environment and fully mineralised, the waste will convert to carbon

dioxide and water and other substances depending whether the degradation goes through aerobically or anaerobically (Figure 2.15).

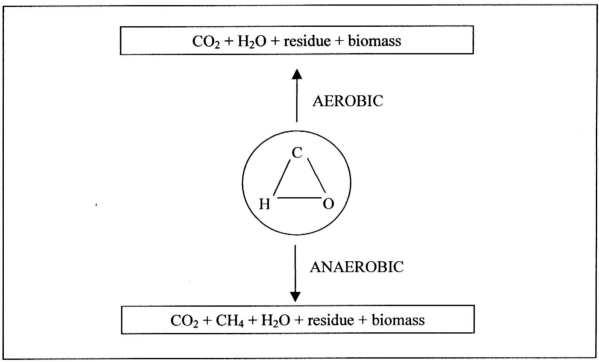


Figure 2.15 Degradation of materials containing C,H,O

Another benefit of biological recycling is, biomass formation where the process 'ties up' the carbon for a more extended period compared to incineration. Thus biological recycling is most environmentally compatible because it does not use a lot of energy compared to incineration or mechanical recycling and the cost is low. Table 2.8 shows the pros and cons of mechanical recycling, incineration and biodegradation (Huang, 1995).

In future, a combination of mechanical recycling, energy recovery by incineration and composting will be a preferred alternative to landfill. This is because different types of plastic require different treatment. Thus to divert as much as plastic waste from landfill, a combination of waste management is the best.

Table 2.8 Advantages and disadvantages of polymer waste management options

Advantages	Disadvantages
Recycling (material, mechanical)	
Process available	Product downgrade
Source reduction	Not easily adopted for mixed plastics
Suitable industrial scraps	High costs of gathering and sorting
Not final disposal	Not efficient for food packaging
Politically favoured	Not a final disposal
Can be done on any scale	
Incineration	
High efficiency for sterilisation	High plant cost
Energy generation	High gathering and sorting costs
Semifinal disposal	Could produce high water and gas pollution
Technology available	Political barrier
	Only applicable to relatively large scale
Biodegradation	
Environmentally compatible and friendly	Not enough reactors/ plants
Completes the carbon and nitrogen cycles	Requires new plastics, additives, etc.
Can be on any scale	Has to overcome the public's misconceptions
	Needs to develop new products

Source: Huang, 1995

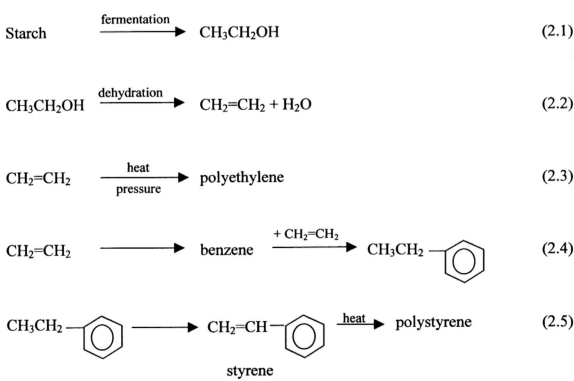
2.3 Environmental Impact of Plastic

Over the last century, synthetic plastics have become the major new materials for everything from replacements for human body parts to the construction of supersonic aircraft and spacecraft. So much so, that plastic production has grown up to a point where the total volume of plastics produced worldwide now exceeds that of steel. The growth has also taken place at the expense of more traditional materials, such as steel, aluminium, paper and glass. The important points that need to be considered are the use of raw materials, energy requirements and pollution during production while generating industrial waste.

2.3.1 Plastics and Raw Materials

Oil and natural gas are the main raw materials used in plastic production. This causes great concern because these are 'non-renewable' resources. Thus their use should be discouraged to extend the useful lifetime of these raw materials for other purposes. Out of the world's total oil and natural gas production, 4% are used for plastics production, the rest are mostly used for transportation and heating (APME, 1999). Plastics made from these raw materials are called synthetic polymers.

Natural polymer is another type of plastic. These are made from renewable resources such as wheat, cellulose, starch and biomass. For example polyethylene was originally produced in Britain by the fermentation of grain to produce alcohol and dehydration of alcohol to produce ethylene. Another example is styrene, where it is produced from starch through several known chemical processes as follows:



However there is drawback when using renewable resources as raw materials, it implies the utilisation of vast areas of agriculture land to provide raw materials. This is unacceptable and unethical as the world currently facing a real problem where millions of people starve daily. Another fact is cost, the grain production cost is many times greater than using gas or coal as raw materials (Guillet,1995).

A study by M. Heyde (1998) in comparing biosynthetic and synthetic polymers concluded:

i. The use of renewable raw material in technical products or consumer goods always requires the additional use of non-renewable resources. Regarding the whole product life cycle the total demand on non-renewable resources can be higher than the demand of a comparable petrochemical product in concrete cases.
ii. Saving resources by using renewable raw material will only be achieved if the whole system is carefully optimised.

Films made from biosynthetic and synthetic polymers may have a wide range of different functionality with properties. However if the application is the same for example as waste bags, the mechanical property 'penetration resistance' may be the crucial functionality. This is because films made from materials such polyhydroxy butyrate (PHB), high density polyethylene (HDPE) or polystyrene (PS) may need different thickness for reaching the demanded penetration resistance. As a consequence the product systems may need different amounts of polymer material to reach the same functionality. For example more PHB may be required than a conventional polymer for a certain application.

Biosynthetic polymer production is a sensitive biological system. Thus any disturbance in the system can cause problems in the total demand of raw material. This shown in the

Figure 2.16 where the total demand of non-renewable, energetically valuable resources for the best investigated case of biopolymers and for the worst case are shown together with the values of HDPE and PS. It can be seen in best case biosynthetic polymer (PHB) need less energetic valuable resources than synthetic polymers. However in worst conditions the energy demand of the PHB system reaches another magnitude (Heyde, 1998).

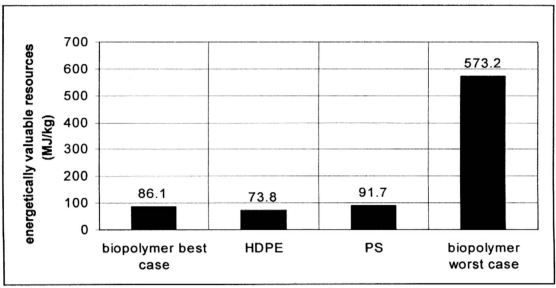


Figure 2.16 Input of energetically valuable resources in the production of polymers Source: Heyde (1998)

2.3.2 Plastics and Energy

Packaging industry is the largest plastic consumption industry. Disposable plastics packaging have received a lot of criticisms because it is considered to waste non-renewable resources and impose unacceptable burdens on municipal disposal facilities. In this section the energy used to produce plastic packaging in comparison with other type of materials is discussed. In addition to that is the energy used to clean returnable glass milk bottles compared to plastic milk bottle is also discussed.

Table 2.9 shows the energy requirements in order to produce one kilogram of various materials for packaging purposes.

Table 2.9 Energy[a] requirements for the production of materials used in packaging

Material	*Energy requirement ($kWhkg^{-1}$)*
Aluminium	74.1
Steel	13.9
Glass	7.9
Paper	7.1
Plastic	3.1

[a]*Energy utilisation is related to cost and to the CO_2 burden on the environment ('greenhouse effect')*
Source: Scott (1999)

From Table 2.9 it is obvious that to produce one kilogram of aluminium it requires up to 24 times more energy than comparable amount of plastic containers. Even steel, glass and paper energy requirement per kg superseded plastic. That is why as consumer demands more, it is more economical to use plastic rather than other traditional materials.

Plastic products can be produced easily in a repetitive process such as injection moulding process. This process can produce a high volume of plastic product in one process. No more different process such as joining procedures required. Thus time and energy can be saved. This is proven in the Table 2.10, where one plastic bottle needs on 0.11 kWh of energy compared to aluminium can which require about 30 times more energy.

Table 2.10 Energy requirements for similar beverage containers

Container	*Energy usage per container (kWh)*
Aluminium can	3.00
Returnable soft drink bottle	2.40
Returnable glass beer bottle	2.00
Steel can	0.70
Paper milk carton	0.18
Plastic beverage container	0.11

Source: Guillet (1995)

Before plastic bottles, returnable soft drink glass bottles was used. This was mostly returnable to traditional sundry shops. This practice was slowly phased out because the growing role of supermarkets as the main outlet for bottled beverages especially in urban areas. Another reason is cleaning and sterilising glass bottles require time, energy and other resource such as water. Table 2.10 shows that one glass bottle needs to be used more than 21 times before the energy used to manufacture is on par with plastic container. However, this does not include the cost and energy used for transporting the glass bottles, cleaning and sterilising this glass bottles. Thus in actual fact more energy is required to use the returnable soft drink bottle.

2.3.3 Plastics and Production Effluents

Production of materials will invariably provide us the goods that we want but also goods that we do not want, production waste. Manufacturing of plastics produces a lot of harmful pollutants which manufacturing companies need to deal with properly. One of the wastes produced is known as sprues and runners and other forms of excess material. To reduce waste, this material can be recycled where they are grounded and

added back to new raw stock. However not all kind of waste can be recycle, because it depends on the type of raw material. Thermoplastic materials can be recycled whereas thermosetting materials cannot be recycled as even the small addition of re-ground materials can reduce the quality of the final mouldings. Thermoplastic materials are polymers that can be softened and formed using heat and when cooled it will take up the shape that they have been formed into. But if heat is reapplied they will soften again. Examples of thermoplastics are acrylic and styrene. Thermosetting polymer is the same with thermoplastic polymer except that when it is heated again they will not soften again. Example is polyester resins used in glass reinforced polymers work (Microsoft Encarta, 2002).

The current trend is to replace plastic grocery bag to paper bags. There is the advantage that paper bags can biodegrade faster than plastic bags. Unfortunately if the shift from plastic to paper is complete there are other things to consider. Paper is generally heavier than plastic, thus the weight of garbage will also increase. In addition to this, manufacturing paper is actually more environmentally polluting than manufacturing polymers. Table 2.11 shows data produced by the West German Federal Office of the Environment, on the air and water pollution associated with the production of 50,000 carrier bags of polyethylene, unbleached kraft paper and 'paper combinations'. The production of plastic carrier bags caused significantly less air pollution, and about 200 times less water pollution compared to that of paper carrier bags.

Table 2.11 Air and water pollution associated with the production of 50,000 carrier plastic bags

Environmental burden	Polyethylene	Unbleached kraft paper	Paper combinations
Energy (GJ) for the production process	29	67	69
Air pollution (kg)			
SO_2	9.9	19.4	28.1
Oxides of nitrogen	6.8	10.2	10.8
Hydrocarbons	3.8	1.2	1.5
CO	1.0	3.0	6.4
Dust	0.5	3.2	3.8
Waste water burdens (kg)			
COD	0.5	16.4	107.8
BOD_5	0.02	9.2	43.1

Source: Scott (1999)

2.3.4 Plastics and Waste

In the 1960s it was predicted that the non-biodegradability of synthetic polymers could present a problem in the long term disposal of packaging made from commodity polymers. Doomsday scenarios began to emerge. Environmental campaigners predicted that by the end of the century, a layer of non-degraded plastic would cover the whole Earth. However this prediction failed to take place because it did not take into account nature's diversity, involving biotic and abiotic chemistry in the bioassimilation of waste and litter (Scott,1999).

The amount plastic waste however keeps increasing. Plastic waste need more time to degrade because of the antioxidant and other additives that was integrated during

manufacture in order to serve its purpose. Although the amount is slightly over 10% of the total municipal waste, the problem of non-biodegradability is highlighted by overflowing landfills, polluted marine waters and unsightly litter (Huang,1995).

In Malaysia the average amount of plastic in Malaysia's urban area in 1999 is about 18%. Table 2.12 shows the plastic contents in a few locations in Petaling Jaya. From here it can be concluded that the more affluent areas produces more plastic wastes. This most probably because the ability of occupants to spend more in supermarket and departmental stores. As mentioned in Chapter One, most of plastic wastes in Malaysia are thrown away in landfill. Table 2.12 also shows that even though weight wise plastic wastes are small in numbers, by volume the wastes showed that they occupied more space. This is because plastics have lower density that means plastic waste takes up more space for relatively little mass as compared to other household and industrial waste. As space for landfill is dwindling, the growing amount plastic waste is a major concern for authorities.

Table 2.12 Plastic contents in wastes from a few locations in Petaling Jaya, Malaysia

Location	Plastic content in waste	
	By Weight	By volume
Kampung Tunku	7.5%	16.7%
Section 17	8.1%	18.1%
Sg Way Low Cost	6.6%	14.7%
PKNS Low Cost	4.8%	10.7%

Source: Gan (2001)

In Western Europe for instance, more than half of plastic waste produced is from households. Heterogeneous materials, particularly residues of foodstuffs, paper labels, metal caps and tags, inks and adhesives, all of which have an adverse effect in mechanical recycling process, contaminate much of the households' waste. These

contaminants can be partially removed by thoroughly washing them but this will create more problems when disposing contaminated wash water. However, relatively uncontaminated single polymer types can be collected from retail outlets by segregation on site for example discarded polypropylene crates, battery cases and supermarket shrink-wrap. These can be recycled with addition of new antioxidants and UV stabilisers without significant loss of mechanical properties (Scott,1999).

Recycling is one of the options for plastic waste management option. There are others to consider as well. These options are important because the regulatory authority in Western Europe have made it clear that manufacturers should also take responsibility in all aspects. Therefore the manufacture's responsibility now covers from resource usage to disposal methods.

2.4 Relevance to Project

Biodegradable plastic is the one of the products resulted from new environmental regulations, societal concerns and increased growing environmental awareness. Composting is one the waste management options that is the most environmentally friendly and it is able to divert some waste from landfills. Since more 60% of average Malaysian's MSW is organic in nature and potentially compostable, composting is one good option. Thus by using biodegradable polymers in the packaging of organic or biodegradable materials, such as kitchen waste, enables this waste to directly composted without the need to separate the contents from the packaging. For example biodegradable plastic garbage bag can be directly composted. Consequently, this can take some of burden from landfill.

The study is to investigate the compostability of biodegradable plastics and its application in Malaysia's solid waste management system. Besides that, the degradation path will also be investigated and the influence of the amount of additives on degradation rate will also be analysed.